

C. Friction-Stir Spot-Welding of High-Strength Steel

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Contractor: Oak Ridge National Laboratory & Pacific Northwest National Laboratory

Contract No.: DE-AC05-00OR22725 & DE-AC06-76RLO1830

Objective

- The primary objective of this project is to evaluate the response of high-strength steels to friction-stir spot-welding (FSSW).
- Phase 1 activities will address the critical questions of whether there are tool materials available that have potential for reasonable life, and whether FSSWs made in high-strength steels represent any real advantage over welds made by conventional processes like resistance spot-welding (RSW).

Approach

- The project is a collaboration between ORNL and PNNL, and it includes an advisory committee with representatives of DCX, Ford, GM, two automotive steel suppliers, and a friction stir welding tool supplier.
- Lap joints will be made and used to correlate tensile shear strength with processing parameters and microstructures.
- Tool durability will be evaluated by sequentially making as many welds as possible with each tool material.
- Some relatively simple process modeling will be done with existing capabilities to identify conditions that could improve the business case situation for the process.

Accomplishments

- This is a new project begun during 2005.
- A consensus was achieved on the sheet steels and friction-stir tool materials to include in the Phase 1 study, and all the materials were acquired.
- A consensus was reached on the initial testing and evaluation plans.

- The test plan was initiated.

Future Direction

- Phase 2 activities will develop process models that include weld performance prediction. They will also evaluate joint mechanical properties, assess the potential for in-process NDE, transfer optimized process parameters to a robotic system, and establish the framework of a design database for spot-friction-welded structures.

Introduction

The technology for implementing friction-stir spot-welding (FSSW) of aluminum in automobile manufacturing environments exists. C-gun-type FSSW welding heads have been developed. They have been adapted to robotic systems, and these FSSW systems for aluminum are commercially available. Important questions remain about effective, economical application of FSSW to steels. The critical information that is unknown for auto steel component construction is whether there are tool materials available that have potential for reasonable life, and whether FSSWs made in high-strength steels represent any real advantage over welds made by conventional processes like resistance spot-welding (RSW). If FSSW of high-strength steels can be demonstrated and its advantages over RSW identified, then it will be possible to consider both a more detailed technical study and broader business case analysis for FSSW of high-strength steels (or any steel) in automobile assembly.

Approach

Three uncoated high-strength steels were selected for the Phase 1 study: (1) dual-phased steel, DP780; (2) a steel with transformation-enhanced plasticity, TRIP780; and (3) a hot-stamp boron steel, HSB (sourced from a Swedish supplier). It was agreed to acquire the material in a thickness of 1.5 mm based both on easy availability from the steel suppliers (Mittal Steel Corp. and Gestamp US Hardtech, Inc) and on the level of interest among OEMs.

Two materials were selected for the friction-stir tools: polycrystalline boron nitride (PCBN) and an alloy of tungsten containing 25 wt% rhenium (W25Re). Both materials are available commercially. Two tool designs, shown in Figures 1 and 2, were selected using input from the industry supplier of the PCBN, MegaStir. The tool design

shown in Figure 1 is considered relatively conventional, having a pin that protrudes from its main body. The main body is referred to as the shoulder region; its diameter is indicated as 0.4 inches in Figure 1. Figure 2 depicts a 'shoulderless' tool. This geometry was recommended by MegaStir based on their

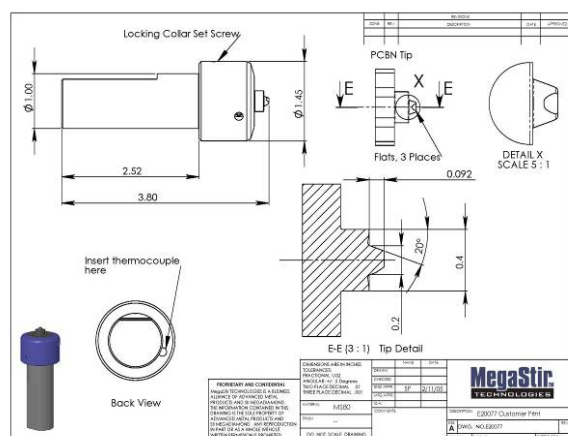


Figure 1. Drawing that illustrates shape of conventional friction-stir pin tool geometry

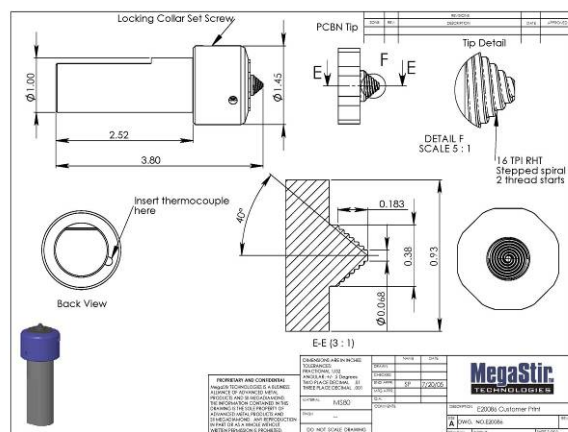


Figure 2. Drawing that illustrates shape of conventional friction-stir shoulderless tool geometry

exploratory work on FSSW. Two tools of each material were made according to both drawings for a total of 4 tools.

Lap joints are being made to measure tension-shear strength, and to correlate strength with processing parameters and microstructures. The spot welds will be made by varying the parameters of tool plunge depth and tool-plunging rate. In addition to these control parameters, a number of other process variables will be recorded for each weld including weld time, spindle torque, normal force, and temperature on the back side of the two-sheet stack-ups.

Joint strength will be correlated with these parameters. Joint strengths will be compared with those of resistance spot-welds using data from published literature and existing databases.

Results and Discussion

Published data indicate the variables of plunge depth and weld cycle time are important for determining spot weld strength in aluminum alloys. Based on this information, the initial testing plan for the high-strength steels was meant to probe this parameter space by plunging to predetermined depths at constant rates, and by including a dwell at the end of each spot-weld program.

The friction-stir machine was used in displacement control during the spot welding. The plunge depths were selected by considering the geometry of the conventional (or pin) tool, Figure 1, and the thickness of the two-sheet stack-ups being used for the welding. The pin extends beyond the plane of the shoulder by about 2.33 mm. The two-sheet stack-up is about 3-mm thick. Consequently, plunging to a depth of 2.3 mm would insert the pin entirely into the stack-up and just start to engage the shoulder of the tool on the surface of the top sheet. Plunging to a depth of 2.9 mm would insert the end of the pin nearly to the bottom surface of the bottom sheet. Based on this reasoning, the plunge depths

were varied from 2.3 to 2.9 mm in 0.1 mm steps. Operating the machine in the displacement mode ensured that the desired final plunge depths were achieved.

Because the friction-stir machine was operated in displacement control, the dwell portions of the welding control programs required special consideration. Using a fixed-position dwell in displacement-control mode would permit the normal load on the tool to decrease due to temperature rise at the dwell position. It is believed that maintaining the loading conditions at the dwell position will promote better bonding. Consequently, incorporation of a dwell was accomplished by creating a two-step welding program that involved first plunging to nearly the full desired depth followed by further plunging the final 0.2 mm of depth at a slower rate. Three initial plunging rates were used: 0.4 mm/s, 2 mm/s, and 3 mm/s. The two secondary plunge rates used were 0.07 mm/s and 0.20 mm/s. These secondary plunge segments produced 'quasi-dwells' of either 1 s or 3 s at the end of each weld program.

Examples of two weld programs are shown in Figure 3. This procedure resulted in 14 individual welding programs at each plunging rate for a total of 42 individual welding conditions. These 42 sets of conditions encompassed total welding times of 1.70 to 9.75 s.

The initial FSSW trials were conducted at ORNL on September 15-16, 2005, Figure 4. At that time only DP780 and the PCBN tools were available. Spot-welds were made using both the conventional tool and the shoulderless tool. Because the time for experimentation was limited, only selected parameter sets were used for the initial welds. Six parameter sets were chosen to produce plunge depths of either 2.3 or 2.9 mm and weld times of 1.70, 2.05, 3.90, 4.35, 6.25, and 9.75 s. Visual appearance of all welds was good. The PCBN tool did not appear to suffer any significant wear. Lap-joint specimens were scheduled for tension-shear testing and microstructure analysis.

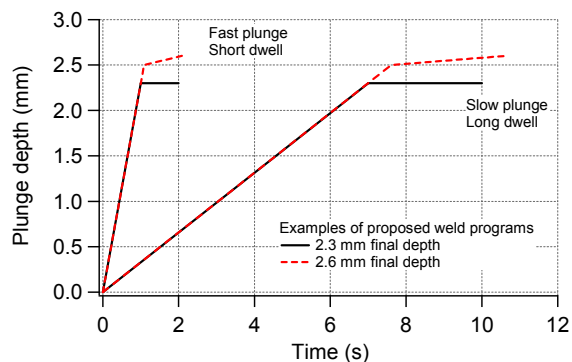


Figure 3. Illustration showing examples of conditions used for friction-stir spot-welding



Figure 4. Participants at initial welding trials held at ORNL. Tsung-Yu Pan (Ford) and Jim Quinn (GM) are seated at the controls for the friction-stir machine. Glenn Grant (PNNL), Russell Steel (MegaStir), and Min Kou (Mittal Steel) observe the proceedings.

Conclusions

Friction-stir spot-welds of acceptable appearance were made on a two-high stack-up of DP780 steel using polycrystalline boron nitride. Two tool geometries were used, that of a conventional pin tool and a shoulderless geometry. Tool wear appeared negligible.

Presentations/Publications/Patents

None